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Drivers of urban and rural residential energy consumption in China from the perspectives of climate and economic effects

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ABSTRACT

In this study, we investigate the driving forces behind the changes in residential energy consumption (REC) in China's urban and rural areas over the 2001–2012 period. Based on the logarithmic mean Divisia index method, the REC changes are decomposed into seven driving forces, which are climate change, energy price, energy expenditure mix, energy cost share (in total expenditure), expenditure share (in income), per capita income and population effects. According to the results, climate effect due to increasing days with abnormal temperature, energy cost share effect characterized by more expenditure to be paid for energy use, income effect describing constant income growth in the residential sector definitely increase REC in both urban and rural areas. In contrast, energy prices and energy expenditure mix effects negatively contribute to the REC increase, respectively because of the increase in energy prices and the transition from the low-priced energy to high-priced energy. Expenditure share and population effects play opposite roles in urban and rural areas, and the reasons and implications are analysed in depth.

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1. Introduction

The residential sector was the third largest energy-consuming sector in 2012, accounting for 10.90% of the total energy consumption in China next to industry (67.47%) and transport, storage,[1] postal and telecommunications services sector (11.49%) (Department of Energy Statistics of National Bureau of Statistic of China, DESNBS, 2013). And, it is meanwhile the fastest-growing sector over the 2001–2012 period in China, increasing from 116.9 million tonnes of coal equivalent (TCE) to 278.2 million TCE. In addition, as shown in Fig. 1, there exist obvious different characteristics of REC growth between the urban and rural areas. The urban REC increases more quickly than the rural REC due to the accelerating urbanisation in China (Li et al., 2015), which reached 52.57% in 2012 according to National Bureau of Statistics of China (National Bureau of Statistic of China, NBS, 2001–2013), and there are several distinct differences between the driving factors of the urban and rural REC growth. In this study, we intend to investigate the driving forces behind REC changes in urban and rural areas in China respectively.

A number of scholars have analysed the driving forces behind REC changes. Using the statistical data based on regression analysis, various scholars have examined the effects of temperature and solar radiation on residential buildings' heating activities to predict buildings' heating energy consumption in the future (Fumo and Biswas, 2015; Raffio et al., 2007; Soldo et al., 2014). Using survey data, several researchers have investigated and predicted REC by calculating prediction variables, such as economic parameters, energy price, income, climate, behaviour and household characteristics (Bianco et al., 2013; Gans et al., 2013; Mardookhy et al., 2014). Mixed using of statistical data and survey data, lifestyle and behaviour effects have been analysed by researchers (Duchin, 1998; Weber and Perrels, 2000; Yohanis, 2012). For example, Bin and Dowlatabadi (2005) found the behaviour habit played important role on REC and CO_2 emissions in the USA, using the consumer lifestyle approach (CLA). Different from the aforementioned

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[1] By storage, we mean the products stored in a warehouse.

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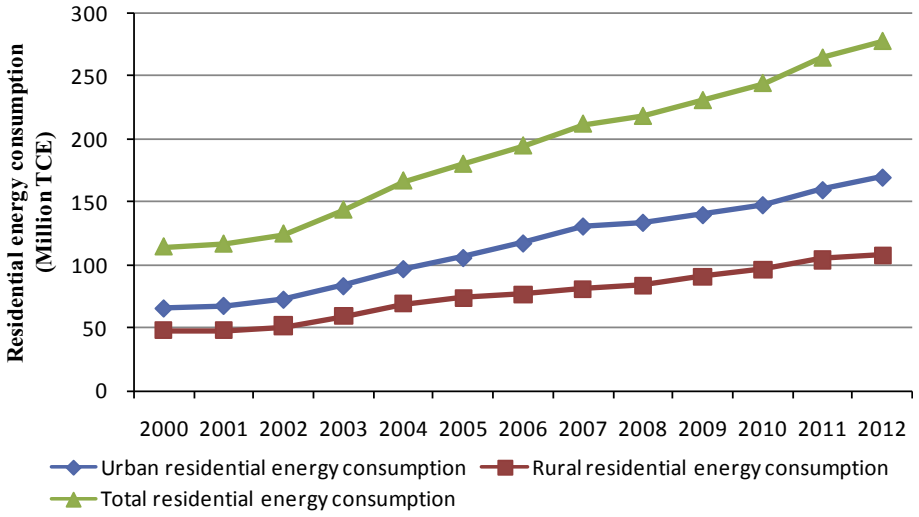

Fig. 1. Urban and rural residential energy consumption (REC) from 2000 to 2012.

studies, decomposition analysis seeks to decompose energy use into multiplication factors to investigate the underlying factors of REC. For example, Haas (1997) decomposed REC changes into nine influencing factors: demographics, economic factors, individual factors, lifestyle, culture, structure, technology, climate and policy. From 2009 to 2017, an increasing number of studies focused on analysing changes in REC and carbon emissions by using index decomposition analysis in countries such as Brazil, Ireland, the USA and China (Achão and Schaeffer, 2009; Rogan et al., 2012; Miao, 2017), most of which were based on logarithmic mean Divisia index (LMDI) method (Xu and Ang, 2014). From the perspective of income, REC was decomposed into energy intensity effect (energy consumption divided by income), income effect, population effect, and so on (Hubacek et al., 2012; Wang et al., 2015; Zha et al., 2010). The results showed that the income effect and the population effect positively contributed to the increase in REC or carbon emissions, whereas the energy intensity effect played a negative role in the changes in REC or carbon emissions. Other scholars decomposed the REC into activity effect (number of households), structure effect (house type effect),[2] intensity effect (energy consumption per household), and so on (Chung et al., 2011; Hojjati and Wade, 2012; Rogan et al., 2012). The activity effect increased REC, whereas the intensity effect played a negative role in REC changes in Hong Kong and the USA but not in Ireland. Interestingly, the house type effect increased REC in Hong Kong but had the opposite effect in the USA and Ireland (Chung et al., 2011; Hojjati and Wade, 2012; Rogan et al., 2012). Nie and Kemp (2014) and Zhang et al. (2016) investigated the influence of the floor space on REC changes. Liu and Zhao (2015) and Zhao et al. (2012) found that energy price restrained REC. Some scholars in Hong Kong (Chung et al., 2011) and Ireland (Rogan et al., 2012) also examined the influence of climate. In Hong Kong, REC for space cooling (few space heating activities due to the hot weather) increased until 2007 because of the climate effect. For Ireland, a positive climate effect on the increase in REC for space heating was found until 2008. Fan et al. (2017) emphasized the important role of urbanisation to REC growth in China and further forecasted that with the deepening of the urbanisation, REC will further increase.

The main points of the aforementioned studies are summarized as follows. First, climate is known as an important determinant of REC through influencing heating and cooling (Rogan et al., 2012; Bianco et al., 2014). Its effect on REC had been proven to be rather significant (Catalina et al., 2008; Min et al., 2010). Additionally, the climate changes a lot in different seasons in China. For example, the temperature in Harbin in the northeast of China changed from −19.4 Celsius degrees in December to 23.9 Celsius degrees in July 2012 (NBS, 2001–2013). However, the influence of climate on REC in China has so far not been investigated by researchers using index decomposition analysis. Second, the price effect in previous studies (Liu and Zhao, 2015; Zhao et al., 2012) was usually measured using REC expenditure divided by REC, which is actually represents average energy price and cannot reflect the effects of individual energy prices and energy expenditure mix. Third, the determinants of REC changes also vary depending on living in urban areas or rural residents (Liu and Zhao, 2015).

In this study, we contribute to existing theoretical framework by investigating the climate effect on urban and rural REC changes in China alongside the influences of other driving forces consisting of energy price, energy expenditure mix, energy cost share (in total expenditure), expenditure share (in income), per capita income and population effects. To our best knowledge, the climate effect has not been included in previous studies. Moreover, we use the individual energy prices instead of average energy price to measure the energy price effect, which excludes the energy expenditure mix effect. Through measuring the climate effect quantitatively and providing the individual energy prices effect, corresponding policy implications are expected to obtain.

The rest of this paper is structured as follows. Section 2 covers the methodology and data sources. The results are presented in Section 3. Section 4 gives a discussion on the decomposition results, and Section 5 summarises the findings and the conclusions.

2. Methodology and data

2.1. Index decomposition analysis model

In this study, we decompose changes in urban and rural REC into several effects within the framework of economic factors, climate effects and population. In doing so, we are able to investigate the influence of urbanisation on REC through an analysis that accounts for changes in income, climate and other factors. Based on theoretical considerations and data availability, we have opted for the

[2] Chung et al. (2011) use the term *household type* to explain the type of each house. In this paper, we use the term *house type effect*.

logarithmic mean Divisia index (LMDI) method in additive form as the basis for our decomposition analysis. The LMDI has several advantages over other index decomposition analysis methods. Relative to the Laspeyres index method, in which the impact of a driving factor is calculated by letting that factor change while holding all the other factors at their respective base year values, LMDI decomposition is more scientific because it satisfies the factor-reversal test by using the additive property of log percent (Ang, 2004; Yi et al., 2016). Moreover, different from the arithmetic mean Divisia index (AMDI), the LMDI offers perfect decomposition results with no residual (Ang, 2004; Rogan et al., 2012; Xu et al., 2014). Finally, next to having a stronger theoretical foundation, the results from the additive form of the LMDI are given in physical units, which are easier to interpret relative to indexes in a multiplicative case (Ang, 2015; Ang and Liu, 2001).

For analysing the climate and individual energy prices effects in depth, the annual aggregate REC in urban or rural areas is disaggregated into seven parts in this study, as follows:

$$REC_i = \sum_j \frac{\tilde{E}_{ij}}{E_{ij}} \times \frac{E_{ij}}{EE_{ij}} \times \frac{EE_{ij}}{EE_i} \times \frac{EE_i}{TE_i} \times \frac{TE_i}{I_i} \times \frac{I_i}{P_i} \times P_i, \quad (1)$$

where the subscripts i and j refer to different regions consisting of urban and rural types, and energy types.

REC_i is the aggregate residential energy consumption in region i,
$\tilde{E}_{ij}$ is the final REC in region i and energy type j affected by climate change,
E_{ij} is the final REC in region i and energy type j without consideration of climate change,
EE_{ij} is the residential energy expenditure in region i and energy type j,
EE_i is the residential energy expenditure in region i,
TE_i is the total residential expenditure in region i,
I_i is the residential income in region i and
P_i is the population in region i.

To interpret the results, we express each factor in Equation (1), as follows:$\omega_{ij} = \frac{\tilde{E}_{ij}}{E_{ij}}$ refers to the climate-adjusted coefficient in region i, representing the climate effect.

$EP_{ij} = \frac{E_{ij}}{EE_{ij}}$ is the energy price effect reflecting the role of changes in energy prices on energy consumption.

$EM_{ij} = \frac{EE_{ij}}{EE_i}$ means the energy expenditure mix effect, referring to the percentage of expenditure for each energy type j in the total energy expenditure in region i;

$EC_i = \frac{EE_i}{TE_i}$ indicates the energy cost share effect, referring to the ratio of REC_i expenditure to the total expenditure in region i;

$EI_i = \frac{TE_i}{I_i}$ denotes the expenditure share effect, referring to the ratio of the total expenditure share to the total income in region i;$IE_i = \frac{I_i}{P_i}$ represents the income effect, referring to the income per capita in region i; and

$PO_i = P_i$ signifies the population effect, referring to the population in region i.

Thus, the decomposition equation could be expressed as follows:

$$REC_i = \sum_j \omega_{ij} \times EP_{ij} \times EM_{ij} \times EC_i \times EI_i \times IE_i \times PO_i. \quad (2)$$

Following Ang's (2005) study, the changes in aggregated REC in urban and rural regions could be further decomposed as follows:

$$\begin{aligned}\Delta REC_i &= REC_i^t - REC_i^{t-1} \\ &= \Delta REC_{ce} + \Delta REC_{ep} + \Delta REC_{em} + \Delta REC_{ec} + \Delta REC_{ei} \\ &\quad + \Delta REC_{ie} + \Delta REC_{po}\end{aligned}$$

$$\Delta REC_{ce} = \sum_j \frac{v_{ij}^t - v_{ij}^{t-1}}{\ln v_{ij}^t - \ln v_{ij}^{t-1}} \ln\left(\frac{\omega_{ij}^t}{\omega_{ij}^{t-1}}\right)$$

$$\Delta REC_{ep} = \sum_j \frac{v_{ij}^t - v_{ij}^{t-1}}{\ln v_{ij}^t - \ln v_{ij}^{t-1}} \ln\left(\frac{EP_{ij}^t}{EP_{ij}^{t-1}}\right)$$

$$\Delta REC_{em} = \sum_j \frac{v_{ij}^t - v_{ij}^{t-1}}{\ln v_{ij}^t - \ln v_{ij}^{t-1}} \ln\left(\frac{EM_{ij}^t}{EM_{ij}^{t-1}}\right)$$

$$\Delta REC_{ec} = \sum_j \frac{v_{ij}^t - v_{ij}^{t-1}}{\ln v_{ij}^t - \ln v_{ij}^{t-1}} \ln\left(\frac{EC_i^t}{EC_i^{t-1}}\right)$$

$$\Delta REC_{ei} = \sum_j \frac{v_{ij}^t - v_{ij}^{t-1}}{\ln v_{ij}^t - \ln v_{ij}^{t-1}} \ln\left(\frac{EI_i^t}{EI_i^{t-1}}\right)$$

$$\Delta REC_{ie} = \sum_j \frac{v_{ij}^t - v_{ij}^{t-1}}{\ln v_{ij}^t - \ln v_{ij}^{t-1}} \ln\left(\frac{IE_i^t}{IE_i^{t-1}}\right)$$

$$\Delta REC_{po} = \sum_j \frac{v_{ij}^t - v_{ij}^{t-1}}{\ln v_{ij}^t - \ln v_{ij}^{t-1}} \ln\left(\frac{PO_i^t}{PO_i^{t-1}}\right)$$

where the subscript t refer to different years, and v_{ij}^t is equal to $\sum_j \omega_{ij} \times EP_{ij} \times EM_{ij} \times EC_i \times EI_i \times IE_i \times PO_i$, and

ΔREC_{ce}, ΔREC_{ep}, ΔREC_{em}, ΔREC_{ec}, ΔREC_{ei}, ΔREC_{ie} andΔREC_{po} represent changes in REC_i due to climate change, energy price, energy expenditure mix, energy cost share, expenditure share, income and population effects, respectively.

2.2. Method of measuring climate effect

The climate effect is represented by the climate-adjusted coefficient which is equal to REC affected by climate change relative to REC without considering the climate change. In addition, the climate effect influences REC by space heating and cooling activities, so we use the sum of heating and cooling degree days to indicate the climate, and further use the ratio of the sum of heating and cooling degree days in year t to the mean of the heating and cooling degree days in the research period to represent the climate effect in year t, as shown in the following Equation (3):

$$\omega_{ij}^t = \frac{\tilde{E}_{ij}}{E_{ij}} = \frac{(HDD + CDD)^t}{(HDD + CDD)^{ave}} \quad (3)$$

where HDD represents heating degree days.

CDD means cooling degree days,
$(HDD + CDD)^t$ denotes the sum of HDD and CDD corresponding to the total REC for space heating and cooling in the whole year t and

$(HDD + CDD)^{ave}$ indicates the average of the sum of HDD and CDD for the 2001–2012 research period, corresponding to the REC for space heating and cooling.

Thus, the ratio of $(HDD + CDD)^{t}$ and $(HDD + CDD)^{ave}$representing the climate effect corresponds to the REC for space heating and cooling in year t relative to the mean of the REC for space heating and cooling for the 2001–2012 period, which is due to the climate in year t. Here, it is necessary to indicate that using the sum of HDD and CDD to represent the climate effect is a common, reasonable way (see Hojjati and Wade, 2012).

Compared to studies in Hong Kong (Chung et al., 2011) and Ireland (Rogan et al., 2012), the climate effect in mainland China is much more complicated due to the huge area and temperature differences in the country. Due to China's enormous size, it is inaccurate to calculate HDD by using the average temperature of all provinces; because of the different temperature in each month, using the average temperature of the whole year is also inaccurate. To overcome these problems, we picked 31 cities in 31 provinces of China and then calculated the HDD and the CDD in these cities. The annual HDD and CDD in China over the 2001–2012 period comprised the sum of the HDD and the CDD in the 31 cities. In order to better represent the temperature in each province, we pick the city in the middle of each province as possible as we can. Of course, temperature differences still exist in different cities inside a province, but we believe that this error is already very limited. Due to the limited availability of temperature data, we used the monthly temperature data to calculate the annual HDD and CDD in each city.

Based on the report from Asia-Pacific Energy Research Centre (APERC, 2001), the HDD and CDD in China are calculated as follows:

$$\begin{aligned} HDD^{t}_{tot} &= \sum_{p=1}^{m}\sum_{q=1}^{n} HDD^{t}_{pq}(m = 31,\ n = 12),\ \text{and} \\ HDD^{t}_{pq} &= \begin{cases} (18 - T_{pq}) \times d_q & \text{if } T_{pq} < 18 \\ 0 & \text{if } T_{pq} \geq 18 \end{cases} \end{aligned} \tag{4}$$

$$\begin{aligned} CDD^{t}_{tot} &= \sum_{p=1}^{m}\sum_{q=1}^{n} CDD^{t}_{pq}(m = 31, n = 12),\ \text{and} \\ CDD^{t}_{pq} &= \begin{cases} (T_{pq} - 26) \times d_q & \text{if } T_{pq} > 26 \\ 0 & \text{if } T_{pq} \leq 26 \end{cases} \end{aligned} \tag{5}$$

where HDD^{t}_{tot} and CDD^{t}_{tot} are the total HDD in year t and the total CDD in year t, respectively, HDD^{t}_{pq} and CDD^{t}_{pq} are the HDD in month q of year t in city p and the CDD in month q of year t in city p, respectively.

T_{pq} denotes the average temperature of month q in city p,
$d_q$is the number of days of month q and
m and n represent the number of cities (31) and the number of months (12) in one year, respectively.

2.3. Data sources

The raw data for this study were collected from multiple statistical yearbooks (Table 1). The temperature, expenditure, income and population data came from China Statistical Yearbooks (CSYs) (NBS, 2002–2013). The REC data were gathered from China Energy Statistical Yearbooks (CESYs), (Department of Industry and Transport Statistics of National Bureau of Statistic of China (DITSNBS) and Energy Bureau of National Development and Reform Commission of China (EBNDRC), 2003–2007; Department of Energy Statistics of National Bureau of Statistic of China (DESNBS) and Department of General Affairs of National Energy Administration (DGANEA), 2008; DESNBS, 2009–2013), and the energy price data were collected from Price Yearbooks of China (PYCs) (Editorial Office of Price Yearbook of China, EOPY, 2002–2013). To eliminate the influence of inflation, we made the data of energy prices, expenditure and income the constant price in 2001.

3. Results and analysis

In this section, we provide the results of decomposition analysis over the 2001–2012 period and further analyse the effects of driving forces behind REC changes in depth. The REC changes in both urban and rural areas were decomposed into seven driving forces: climate, energy price, energy expenditure mix, energy cost share, expenditure share, income and population effects, which are analysed in the following subsections. Additionally, because energy cost share effect and expenditure share effect are both part-to-total amount ratios, we analysed the two effects together and named them ratio effects.

3.1. Driving factors of urban REC

As shown in Table 2 and Fig. 2, urban REC increased from 67.48 million TCE to 169.99 million TCE over the 2001–2012 period, with an increase of 102.51 million TCE. The urban REC kept on increasing over the research period. However, in 2001–2002, 2007–2008 and 2008–2009, the urban REC increased relatively slowly, whereas in 2003–2004 and 2006–2007, the urban REC rose relatively fast. Amongst the driving forces, income, population, climate and energy cost share effects positively contributed to the increase in

Table 1
The description of data used in this study.

Data name	Data description	Data sources	Period
Residential energy consumption (REC)	The urban REC includes coal, electricity, gasoline, diesel oil, LPG, Natural Gas, Heat and Gas. And the rural REC includes coal, electricity, gasoline, diesel oil and LPG. And the REC data includes converting data and standard data. The converting REC data is used to calculate energy expenditure and the standard REC data is used to measure aggregated residential energy consumption.	China Energy Statistical Yearbooks (CESYs)	2001–2012
Temperature	The temperature data includes mean monthly temperature in 31 provinces in China.	China Statistical Yearbooks (CSYs)	2001–2012
Expenditure	The expenditure data includes urban residential expenditure and rural residential expenditure.		
Income	The income data includes urban residential income and rural residential income.		
Population	The population data is divided into urban population and rural population.		
Consuming price index (CPI)	The CPI is used to eliminate the influence of inflation.		
Energy prices	The energy prices data is actual prices of each residential energy type.	Price Yearbooks of China (PYCs)	2001–2012

Table 2
Decomposition results of urban REC from 2001 to 2012 in the unit of 10,000 TCE

Period	Climate effect	Energy price effect	Energy expenditure mix effect	Energy cost share effect	Expenditure share effect	Income effect	Population effect	REC changes
01–02	−474.00	78.22	−175.88	385.29	−500.12	881.09	305.76	500.34
02–03	511.82	−261.07	−171.02	164.23	−165.59	669.97	327.96	1076.30
03–04	−564.48	−221.28	14.64	1204.08	−51.47	662.99	321.33	1365.80
04–05	1186.02	−372.95	−370.28	−493.07	−344.68	929.45	353.25	887.75
05–06	−972.57	−610.99	133.49	1237.42	−138.59	1104.85	404.10	1157.71
06–07	−619.35	−526.59	−381.35	1285.58	−320.11	1422.97	488.40	1349.56
07–08	953.31	−574.71	87.79	−1388.50	−222.93	1066.01	380.42	301.38
08–09	116.06	−145.59	−101.42	−1026.38	41.34	1283.16	455.00	622.17
09–10	545.68	−844.52	−152.91	−344.32	−32.15	1081.46	539.51	792.76
10–11	188.52	−144.70	−138.34	−606.83	180.76	1239.90	475.11	1194.43
11–12	425.12	−440.48	−408.11	−212.31	−376.89	1521.28	494.36	1002.98
Total	1296.12	−4064.68	−1663.38	205.21	−1930.43	11863.13	4545.20	10251.17

Data sources: China Statistical Yearbooks, China Energy Statistical Yearbooks, Price Yearbooks of China (2002–2013) and authors' calculations (constant price in 2001)

urban REC, whereas energy price, energy expenditure mix and expenditure share effects played negative roles in the increase in urban REC. However, the seven driving forces showed different impacts on the changes in urban REC in the sub-periods, which are interpreted in the following subsections.

3.2. Driving factors of rural REC

Table 3 and Fig. 3 show the results of the decomposition analysis of the changes in rural REC, indicating an increase of 60.38 million TCE in rural REC, from 46.98 million TCE to 107.36 million TCE over the 2001–2012 period. The rural REC also kept on increasing over the whole period, but the growth sizes in each sub-period differed. The growth rates in rural REC in 2005–2006, 2007–2008 and 2011–2012 were relatively lower, whereas those in 2002–2003, 2003–2004 and 2010–2011 were relatively higher. Seven driving factors influenced the changes in rural REC, in which energy price, energy expenditure mix and population effects negatively contributed to the increase in rural REC. Differing from the situation of urban REC, the energy expenditure mix effect had the largest contribution in the rural area. In contrast, the other four driving forces played positive roles in the increase in rural REC, to which income and energy cost share effects contributed largely.

3.3. Climate effect

The climate effect influenced space heating and cooling activities in the residential sector over the 2001–2012 period. Overall, the climate effect positively contributed to the increase in REC, owing to the increase in the sum of HDD and CDD in China. In particular, the climate effect contributed negatively to the increase in REC before 2007; afterwards, it increasingly contributed to the growth in REC due to the increase in days with abnormal temperatures. This finding is applicable in urban and rural areas at the same time. Table 2 and Fig. 2 show the climate effect in urban China. The REC decreased in 2001–2002, 2003–2004, 2005–2006 and 2006–2007 and increased in the other sub-periods, especially in the second half of the study period. The climate effect played an important role in the REC changes in each sub-period, especially in 2004–2005, when the climate effect acted as the most important driving factor. As shown in Table 3 and Fig. 3, the climate effect in rural China influenced REC changes similar to those in urban China. The climate effect performed a significant role in the REC changes in most of the sub-periods, especially in 2004–2005, when the climate effect decreased rural REC by 8.33 million TCE, as the largest driving factor.

Based on the above-mentioned findings, the climate effect

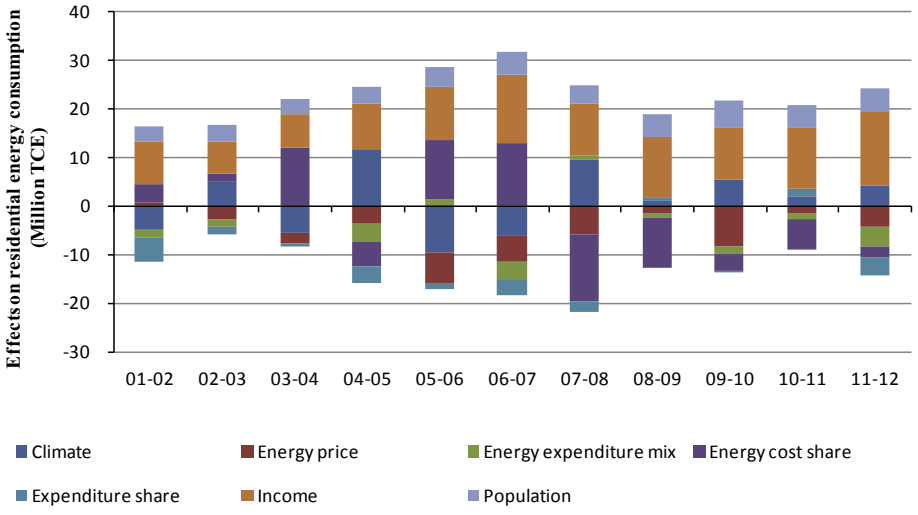

Fig. 2. Decomposition results of urban REC from 2001 to 2012.
Data sources: China Statistical Yearbooks, China Energy Statistical Yearbooks and Price Yearbooks of China (2002–2013) and authors' calculations (constant price in 2001)

Table 3
Decomposition results of rural REC from 2001 to 2012 in the unit of 10,000 TCE

Period	Climate effect	Energy price effect	Energy expenditure mix effect	Energy cost share effect	Expenditure share effect	Income effect	Population effect	REC changes
01–02	−330.87	48.25	−143.65	634.34	5.82	240.32	−81.79	372.42
02–03	360.77	496.27	−523.82	582.79	−208.79	228.97	−98.21	837.99
03–04	−400.61	−393.01	−5.43	1538.03	−96.98	422.10	−95.80	968.31
04–05	832.83	−172.07	−554.24	−344.80	233.85	576.59	−109.79	462.38
05–06	−653.14	−1346.14	−61.58	1828.30	56.45	616.56	−140.24	300.21
06–07	−391.46	186.02	−931.28	1139.91	−135.45	711.23	−180.06	398.91
07–08	591.61	−374.14	131.22	−627.91	112.52	629.58	−126.86	336.02
08–09	73.68	−244.56	182.21	220.71	−123.18	715.35	−182.26	641.95
09–10	352.85	−40.11	−322.87	34.96	−160.23	960.14	−249.51	575.24
10–11	122.48	42.88	−386.32	−396.62	577.31	1080.49	−219.35	820.86
11–12	272.59	−46.18	−382.20	−314.87	−46.04	1073.33	−233.42	323.22
Total	830.74	−1842.77	−2997.96	4294.85	215.29	7254.67	−1717.29	6037.51

Data sources: China Statistical Yearbooks, China Energy Statistical Yearbooks, Price Yearbooks of China (2002–2013) and authors' calculations (constant price in 2001)

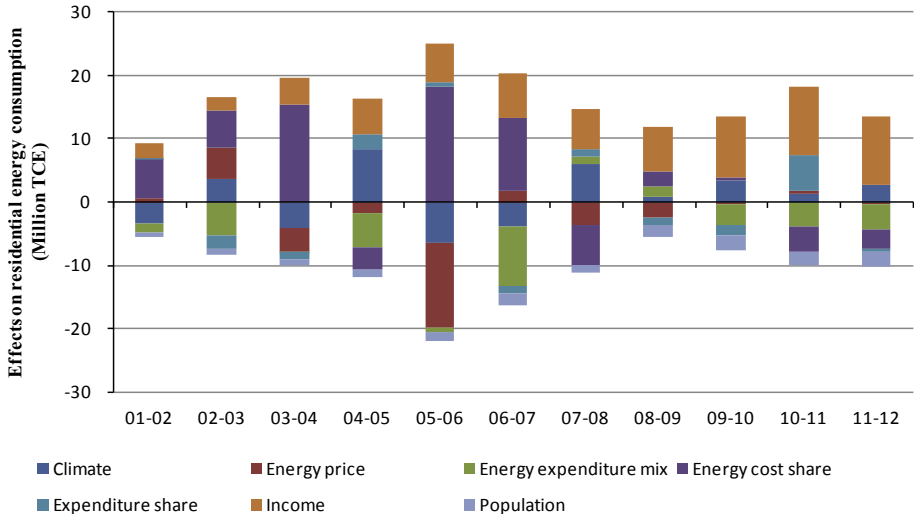

Fig. 3. Decomposition results of rural REC from 2001 to 2012.
Data sources: China Statistical Yearbooks, China Energy Statistical Yearbooks and Price Yearbooks of China (2002–2013) and authors' calculations (constant price in 2001)

played a significant role in the REC changes in urban and rural China. Possible reasons could be that the increasing HDD and CDD in China lead to more energy consumption for space heating and cooling if it wants to keep constant temperature. Table 4 clearly shows that the total degree days varied significantly from year to year, especially in 2004–2005. The change in the total degree days comprised nearly 9000° days, representing the greatest change in the entire period. Additionally, the climate effect influenced REC in urban and rural areas by working on space heating and cooling activities, which are amongst the most important activities in REC.

Furthermore, a large gap existed between HDD and CDD (Table 4), which is consistent with the fact that there are more heating degree days than cooling degree days in China as the average temperature is below 18 °C for most areas and the energy used for space heating was much greater than that used for space cooling in China. The values of HDD reached the lowest in 2007 and then rose gradually since then because the average temperature in the winter in China rose before 2007 and declined after 2007.

3.4. Energy price effect

In both urban and rural areas of China, the energy price effect had shown a strong utility to inhibit REC, owing to the increase in energy prices over the research period. In urban areas, the energy price effect had inhibited the REC growth, except during the 2001–2002 sub-period. In most of the sub-periods, the energy price effect played one of the most important roles in decreasing REC in urban areas. Compared to urban areas, the energy price effect on the inhibition of rural REC growth was less obvious, especially in 2001–2002, 2002–2003, 2006–2007 and 2010–2011,

Table 4
HDD and CDD in the period 2001–2012 in the unit of degree days.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
HDD	70257	65937	69963	65997	73554	67113	64152	69732	69456	72336	73698	75429
CDD	2898	2424	3051	2571	3543	3540	3054	2499	3390	3327	2898	3168
Total	73155	68361	73014	68568	77097	70653	67206	72231	72846	75663	76596	78597

Data sources: China Statistical Yearbooks (2002–2013) and authors' calculation.

Table 5
Energy prices in the period 2001–2012 in the unit of Yuan/TCE.

Energy type	Coal		Electricity		Gasoline		Diesel Oil		LPG		Natural Gas	Heat	Gas	Price index
Areas	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Urban	Urban	
2001	410	399	3637	3629	2403	2401	2299	2297	2074	2072	1254	2589	4706	1651
2002	408	394	3751	3727	2212	2197	2141	2126	2019	2005	1237	2518	4713	1675
2003	363	345	3881	3832	2627	2591	2389	2357	2151	2122	1861	2533	4578	1744
2004	400	375	3841	3727	2877	2796	2490	2420	2206	2145	1505	2707	4640	1803
2005	407	379	3857	3727	3233	3124	2894	2796	2641	2553	1481	2470	4882	1962
2006	509	480	3946	3816	3395	3280	2842	2746	3207	3099	1425	2142	4812	2148
2007	502	469	3775	3621	3704	3549	3401	3259	3064	2935	1444	2620	6538	2341
2008	548	510	3580	3401	4068	3865	3807	3618	3326	3160	1450	3034	6003	2419
2009	596	548	3613	3409	4105	3877	3712	3506	2773	2619	1553	3171	6805	2448
2010	612	539	3531	3328	4831	4546	4164	3918	3184	2996	1536	3574	8209	2600
2011	619	542	3385	3173	4888	4577	4503	4217	3372	3158	1459	3845	9928	2658
2012	625	552	3295	3092	4908	4605	4523	4244	3412	3202	1429	4859	9657	2801

Data sources: China Statistical Yearbooks, China Energy Statistical Yearbooks, Price Yearbooks of China (2002–2013) and authors' calculations (constant price in 2001)

when the energy price effect positively contributed to the rural REC growth.

The positive and negative effects on REC growth could be attributed to the decline and increase of energy prices respectively. We established an energy price index, indicating the average energy price that was calculated by dividing the total energy expenditure by the total REC. The index showed the constant increase in residential energy prices over the research period, which is in line with the previous studies on REC in China that energy prices effect is generally regarded as an important factor to inhabit REC (Liu and Zhao, 2015; Zhao et al., 2012).

However, we find a positive contribution of energy prices effect to REC increase in some sub-periods. To further interpret the uncommon roles of energy prices, we calculated the price of each energy type, using the constant price in 2001 and the constant unit of *Yuan* per TCE (Table 5). In particular, the positive effect of energy prices in urban areas happened in the sub-period 2001–2002, which could be attributed to the decline in most residential energy prices. In rural areas, the energy price effect played positive roles in the REC increase in more sub-periods. In 2001–2002, rural residential energy prices obviously declined, except the electricity price, which positively contributed to the REC increase. In 2002–2003, though most rural energy prices increased, the coal price considerably declined from 394 to 345 *Yuan* per TCE, which increased the consumption of coal, accounting for 77% of the total rural REC in 2002. In 2006–2007, owing to the decline in the prices of coal and electricity as the two largest energy types in rural REC, the energy price effect obviously increased rural REC. In 2010–2011, due to the substantial drop in the electricity price as the second largest rural residential energy type, the energy price effect slightly increased rural REC.

3.5. Energy expenditure mix effect

The energy expenditure mix effect, the percentage of expenditure for various types of energy in the total energy expenditure, negatively contributed to the REC increase in the research period. Through a comparison with the energy price index (Table 5), we got the price level of each energy type. And we defined the high-priced energy and low-priced energy as the energy which price is higher and lower than energy price index respectively. The negative roles of energy expenditure mix effect during most of the sub-periods in both urban and rural areas are due to the transition of expenditure from low-priced to high-priced energy. According to the results, urban and rural areas had different allocations of energy expenditure. Urban energy expenditure was allocated to eight types of energy, and the energy expenditure mix changed a lot from 2001 to 2012. In detail, electricity, liquefied petroleum gas (LPG) and gas were the three largest types of energy, accounting for 66% of the total energy expenditure in 2001, whereas electricity, heat (district heating) and gasoline became the three largest types of energy, accounting for 62% of the total energy expenditure in 2012. Due to the transition to the high-priced energy expenditure structure, the energy expenditure mix effect decreased REC in most sub-periods, excluding 2003–2004, 2005–2006 and 2007–2008. We investigate these periods in more detail to explain the uncommon contribution of the energy expenditure mix effect. In 2003–2004, the decline in high-priced energy, such as gas and electricity, and the increase in low-priced energy, such as diesel oil and heat, indicated greater expenditure on low-priced energy types, which then increased REC correspondingly. In 2005–2006, the positive contribution of the energy expenditure mix effect was due to the increase in expenditure on low-priced coal and the decline in expenditure on high-priced electricity. On the other hand, the positive contribution of the energy expenditure mix effect in 2006–2007 could be explained by the increase in expenditure on low-priced natural gas and heat and the decline in expenditure on high-priced gas and electricity.

In rural areas, energy expenditure was allocated to five types of energy, including coal, gasoline, diesel oil, LPG and electricity. The energy expenditure transitioned from low-priced coal and electricity to high-priced gasoline, diesel oil and LPG over the 2001–2012 period, leading to the REC decline. However, the opposite situations happened in 2007–2008 and 2008–2009, when the energy expenditure mix effect positively contributed to the REC increases in rural areas due to the transition to the low-priced energy structure during these sub-periods. In detail, the increase in expenditure on low-priced coal led to the positive contribution of the energy expenditure mix effect in 2007–2008, whereas the positive contribution of the energy expenditure mix effect in 2008–2009 was due to the decline in expenditure on diesel oil with relative higher price than the energy price index.

3.6. Ratio effects

Ratio effects involve energy cost share effect and expenditure share effect, corresponding to the ratio of energy cost to total residential expenditure and the ratio of total residential expenditure to total residential income, respectively.

The energy cost share depends on how many percentages of expenditure the residents would like to pay for the energy use, which is the result of income and the extent of energy demand satisfaction. The energy cost share effect contributes analogously to

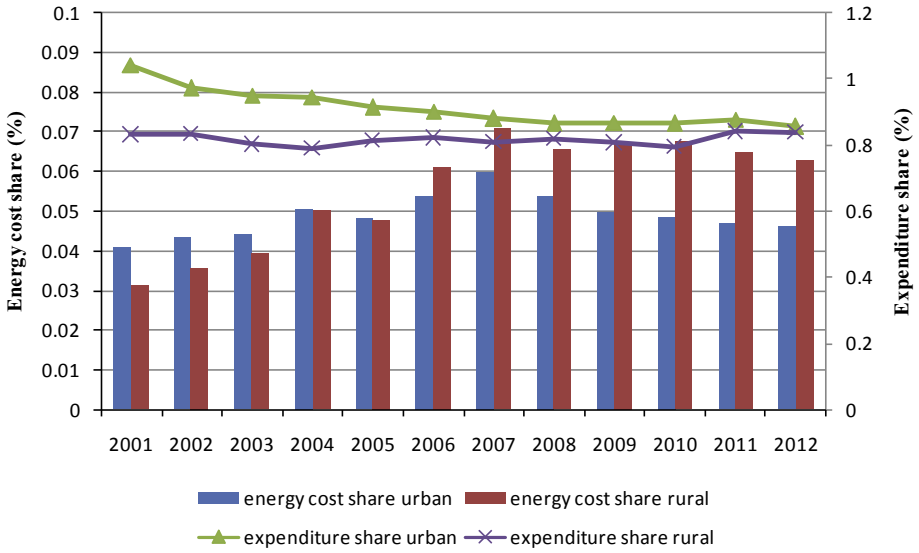

Fig. 4. Energy cost share and expenditure share in urban and rural areas in China over the 2001–2012 period.
Data sources: China Statistical Yearbooks and China Energy Statistical Yearbooks (2002–2013) and authors' calculations

REC change in urban and rural areas. In urban areas, the percentage of energy cost share in total expenditure grew with fluctuations in the first half of the research period until 2007 and then kept declining in the second half, indicating that the basic energy demand had been satisfied in the urban residential sector since 2007 (Fig. 4). In rural areas, the percentage of energy cost share in total expenditure grew much faster than that in urban areas before 2007, and then a drop on a small scale emerged (Fig. 4). These findings indicated a large gap between energy consumption and energy demand, especially in the beginning of the research period, but with the increase in rural residential incomes, people started to spend more on energy consumption. As a result, the gap between consumption and demand gradually narrowed. The basic energy demand of rural residents had been satisfied since 2007. However, compared with the percentage of energy cost share in total expenditure in urban areas, the percentage in rural areas was still high owing to their low incomes.

The expenditure share effect played different roles in urban and rural REC (Fig. 4). In urban areas, the expenditure share effect negatively contributed to the REC increase due to the decline in the percentage of expenditure share in income. This decline can be explained by the increase in income and the uncertainty about the future. For example, people had to save money for their healthcare and pensions in the future because the insurance companies could not cover the large expenditures for both items. However, in rural areas, the expenditure share effect positively contributed to the REC increase on a limited scale due to the small growth in the percentage of expenditure share in income. Even though the rural residents prefer saving to expenditure because of the uncertainty about the further, it was impossible to increase the percentage of savings from their incomes owing to their low incomes and the rigidity of expenditures.

3.7. Income effect

The income effect contributed most to the REC increase in both urban and rural China due to the constant income growth in the residential sector. According to the data from National Bureau of Statistics of China (NBS, 2001–2013), the income per capita in urban areas increased from 6813 to 18,391 *Yuan* over the 2001–2012 period, about three times higher. Meanwhile, the income per capita in rural areas rose from 2350 to 5927 *Yuan* over the same period, more than two times higher. It is easy to find the gap between urban and rural incomes per capita, and due to the faster growth in urban income per capita, the gap gradually widened over the research period. As a result, the energy expenditure in rural areas was allocated to the necessary and low-priced energy types relative to that in urban areas.

3.8. Population effect

The population effect played opposite roles in the REC changes in urban and rural China. In urban areas, the population effect positively contributed to the REC increase owing to the urban population growth. In rural areas, the effect negatively contributed to the REC increase due to the decline in the rural population. The migration of the population from rural to urban areas could be explained by the development of urbanisation over the research period. As a result, the urban population increased from 481 million to 712 million, whereas the rural population declined from 796 million to 642 million over the same period. Until 2012, the urban population had surpassed the rural population with the urbanisation process.

4. Discussions

The decomposition analysis based on a same framework gives us opportunity to compare the driving factors between urban and rural areas. Through the comparison of each driving factor, we found that expenditure share and population effects played opposite roles in the changes in urban and rural REC. The opposite expenditure share effects on REC in both areas could be explained by expenditure share changes in the two areas. In urban areas, residents have begun to save with rising incomes, which led to the decline of expenditure share in income. On contrary, in rural areas, owing to the low income, residents have to spend more rising income on the necessary living expenses, which led to the increase of expenditure share. The population effect increased REC in urban areas and decreased REC in rural areas due to the rural-to-urban migration of the population. Overall, urbanisation was associated

with an increase in REC because of various underlying factors (higher income, etc.). Thus, we strongly suggest the adoption of different energy policies according to the respective characteristics of urban and rural areas. For instance, the policies on energy labels in appliances that were issued in 2005 worked well in urban areas, whereas in rural areas, it failed to perform well due to the residents' lack of ability to pay for the initial investment in energy-efficient appliances (Shen and Saijo, 2009).

Moreover, we include climate as a REC determinant in China, which is a significant driving factor and has not been analysed in previous studies on REC in the country by using the decomposition analysis methodology. Previous studies (Liu and Zhao, 2015; Zhang and Guo, 2013; Zhao et al., 2012; etc.) of REC in mainland China, from the income perspective, attributed the increase in REC mainly to the growth in income and population. By introducing the climate effect, we argue that it is actually one of the most important driving forces of REC in China, which had been ignored by previous studies. Furthermore, by quantitatively measuring the climate effect on the REC changes in China, we provide a more adequate and reasonable explanation of such changes based on decomposition analysis. The new finding about the remarkable climate effect on REC in China can also contribute to policymaking. For example, the national energy-efficient design standard for buildings developed by the China Ministry of Construction in 2005 set a target for new residential buildings to reduce energy consumption by 50% compared to pre-existing buildings (Zhou et al., 2010). Nonetheless, based on our new finding, we argue that the energy consumption reduction target without considering the climate effect is imprecise. For instance, in the period 2007–2008, the urban REC increased 9.53 million TCE due to climate change. Thus the energy consumptions in new residential buildings were significantly overvalued due to the impact of climate change. So we strongly recommend to measure the climate change effect for consideration when making relevant policies.

Furthermore, by using individual energy price instead of average energy price, we found a difference compared to previous studies. Liu and Zhao (2015) concluded that the energy price effect constantly decreased REC in China. We argue that the energy price effect did not constantly contribute to the REC decline in 2001–2012. Liu and Zhao (2015) used the ratio of total REC to total REC expenditure to represent the energy price effect, without considering the price of each energy type. However, because the total price is calculated from the ratio of REC to REC expenditure, the total price is influenced by the actual energy prices and REC allocation in various types. For example, assuming no change in energy prices, if the amount of high-priced energy increases, the total price will increase correspondingly. In our study, the energy price effect is calculated based on the prices of various energy types rather than the average price. Therefore, the energy price effect in our study is the actual effect from the energy price, which could explain the different driving effects between the two studies.

Last but not least, by analysing the energy expenditure mix effect, we found that with the development of China's economy and the increase in residential incomes, an increasing number of people used cleaner and more convenient energy types in both urban and rural areas. As a result, people spent more on high-priced energy, which led to the reduction in energy consumption in China's residential sector. The final energy expenditure allocations in 2012 differed in urban and rural areas. In urban areas, people spent mainly on electricity, heat and gasoline, whereas rural residents preferred spending on electricity, gasoline and coal. This difference indicated that the energy price in rural areas continued to be the most important factor influencing rural residents' decision because they chose coal rather than LPG as the main energy source for space heating and cooking.

5. Conclusions

In this study, we investigated the driving forces behind the REC changes in China's urban and rural areas. Aided by an LMDI model in additive form, we decomposed the changes in urban and rural REC into seven driving forces, consisting of climate, energy price, energy expenditure mix, energy cost share, expenditure share, income and population effects over the 2001–2012 period. The results indicated that the seven driving forces played different roles in the REC changes in urban and rural China. The climate, energy cost share and income effect performed similar functions in the REC changes in both urban and rural areas, which contributed positively to the REC increase over the research period. The energy price and energy expenditure mix effects consisted of a decline in REC in both urban and rural areas. The expenditure share and the population effects played opposite roles in urban and rural areas in China.

Some findings were obtained by analysing the driving factors in depth. First, we discovered a significant gap between urban and rural REC due to the difference of income level, which had become wider in the research period with the improvement of urbanisation rate and the expansion of income gap. Second, climate as an important driving factor, could be used to explain part of the REC increase especially in the second half of the research period, which should be considered in policy making process in the future. Third, the energy prices increase is not the only factor which inhabit REC increase, but the transition of expenditure from low-priced to high-priced energy also played a large role on restraining REC increase.

Note: energy cost share urban and energy cost share rural refer to energy cost share in total expenditure in urban and rural areas respectively in the unit of percentage. And expenditure share urban and expenditure share rural refer to expenditure share in income in urban and rural areas respectively in the unit of percentage.

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